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METALS & ALLOYS

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INCLUDING
CURRENT METALLURGICAL ABSTRACTS

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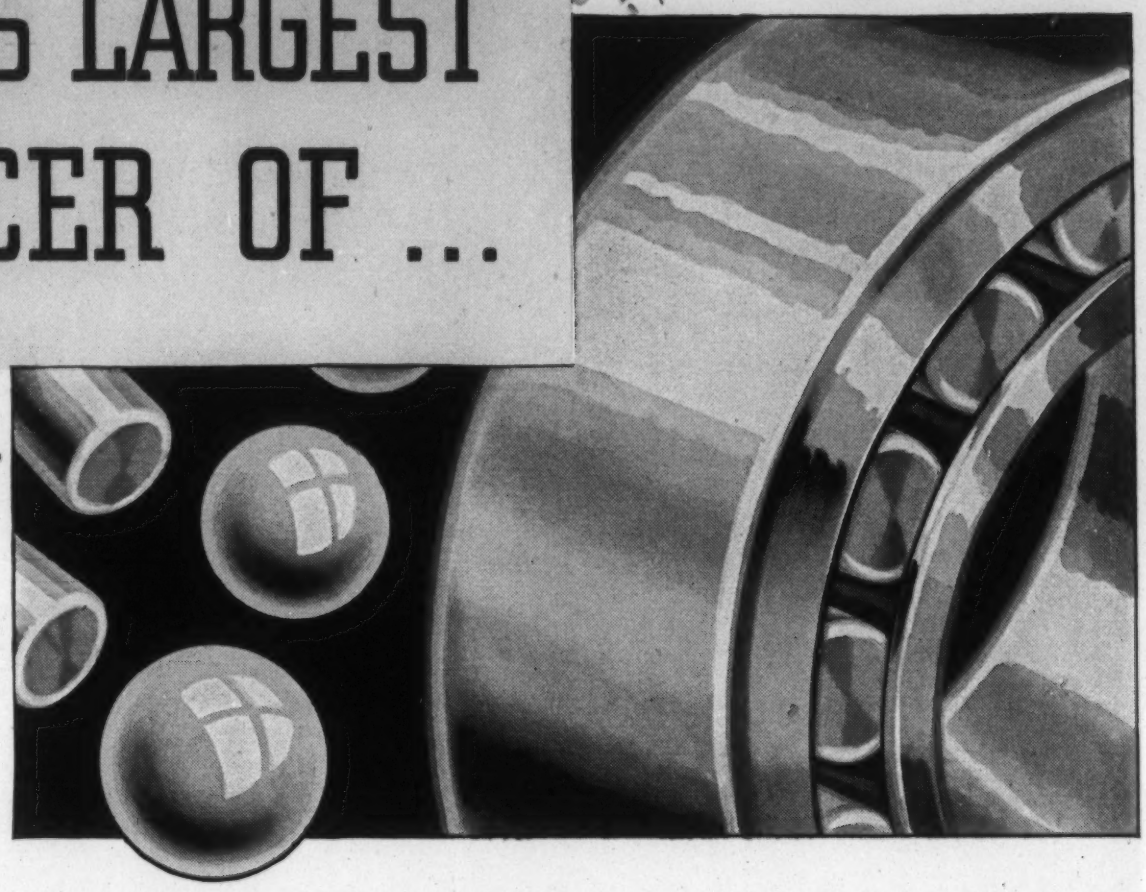

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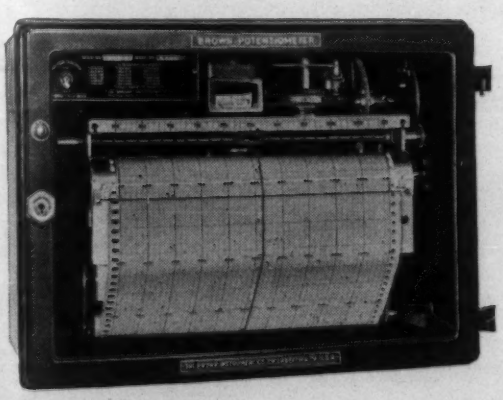

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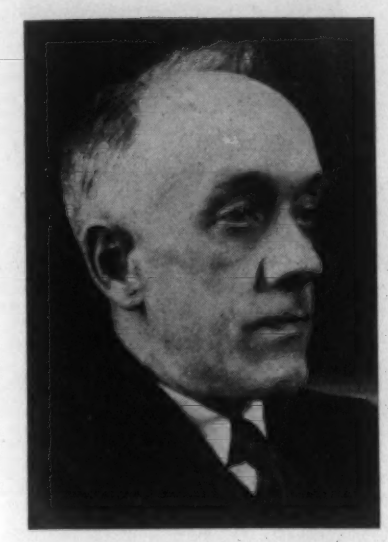


AT THE Metallurgical Advisory Board dinner in Pittsburgh last fall, Mr. Van Deventer, the editor of our able contemporary, *The Iron Age*, discussed the future of the steel industry, before a large gathering of executives and metallurgists of the steel industry. One point of his message will bear repetition and consideration by other industries.

His advice was for each industry to cultivate the "supremacy areas" of its own product. Any material that has no competitors for a given purpose does not have to be sold, it sells itself. If one wants an insurance policy or an automobile (or having the automobile, wants the insurance policy), he can choose from a dozen policies or a dozen cars that will each serve equally well. Hence, the insurance salesman and the car salesman have a tough time in selling to a given prospect. The more unique the policy or the more the car stands out above its fellows, the easier the sales task.

Of course, supremacy may reside in price as much as in intrinsic properties, but whenever the sum total of all the reasons for its use clearly makes a given product outclass its possible substitutes, all that is necessary is to state the facts clearly so they will be understood and accepted. The "better mouse trap" idea still holds.

This works out in the metallurgical field. The aluminum industry does not put high pressure salesmen at work trying to sell aluminum sinkers to fishermen; it knows that lead is the proper material for sinkers. Nor does the lead industry try to sell lead sheet for airplane wing coverings.

But in fields where the fitting of fundamental properties to uses is less striking, we find competition. Aluminum contends with cast iron for pistons, with copper for conductor cable, and with stainless steel for aircraft use, because each of the competing materials has some property advantageous for the particular purpose that is not inherent in aluminum, and which the user must balance against the advantage of lightness of aluminum.

Such struggles bring progress, for the established material must be constantly improved and advanced engineering methods be developed to make the most of its inherent properties, in order that it may not lose too much of its market to a better-developed substitute. When the margin of superiority is slight, the factor of engineering service to customers, more effectively rendered by the makers of one material than by those of its competitors, or the availability of accurate data helpful in engineering design, may swing the balance.

These factors are being given much attention by such groups as the makers of aluminum, nickel and zinc, by trade associations such as those dealing with copper and lead, and by the various groups concerned with modern cast iron and malleable. They are diligently seeking the fundamental facts as to supremacy areas, putting these facts into data sheets, handbooks and the like and concentrating their sales efforts on getting these facts into the hands and minds of those who must choose among different alloys.

As a corollary, there is more and more willingness to concede to other alloys and to non-metallic materials, those uses for which the other materials are really better fitted, and not to put sales effort on selling things that won't stay sold.

The maker of a product that has only a small volume of use but for which there are no real substitutes has an easier time these days than does the maker of a tonnage product that comes from many competing plants. Research and development are rightfully being aimed at closer delineation of supremacy areas. A great deal of such research is particularly well adapted to coöperative attack. The best antidote to the depression, for a firm or an industry, is a product that is sitting pretty in the center of a supremacy area with the boundaries clearly defined. Most everything has a supremacy area or could develop one, if we really knew enough about it.—H. W. GILLETT

◆ ◆ ◆

Chuckles

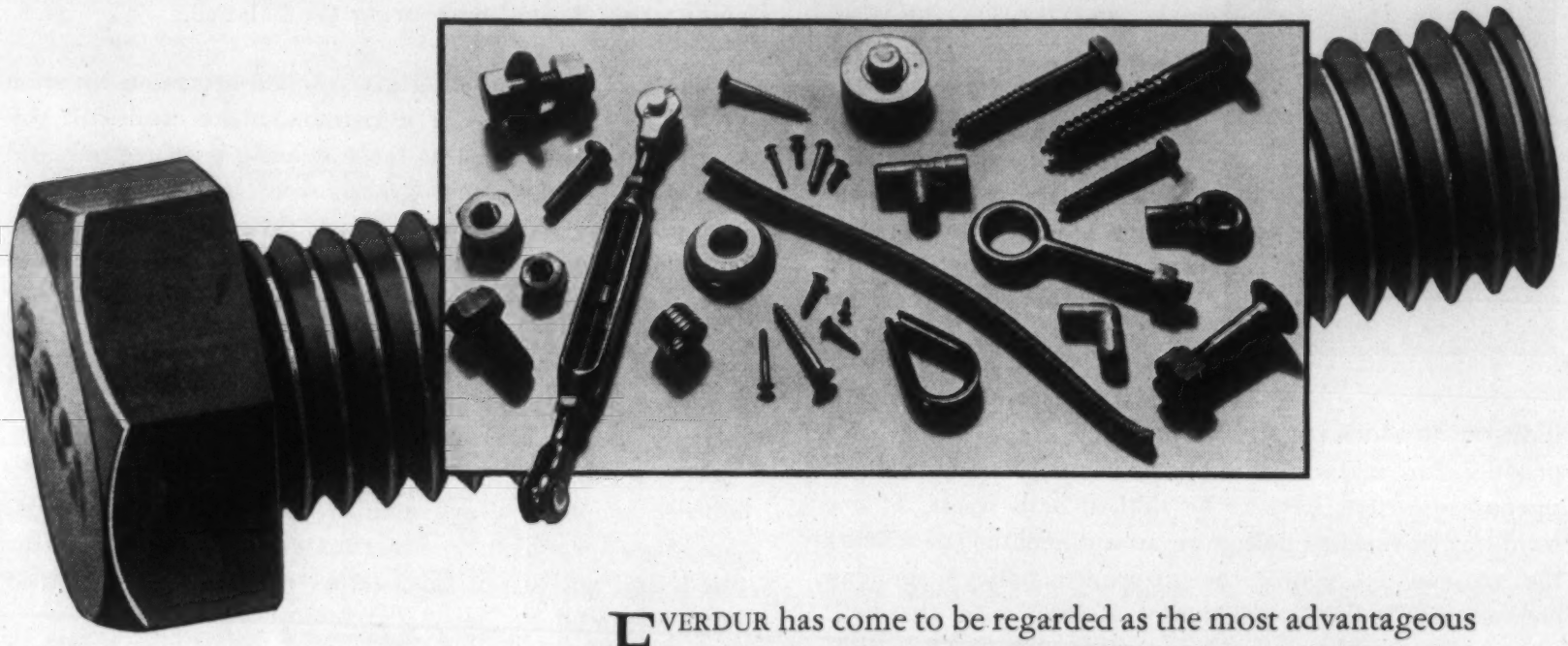
IN STEVENS Master Specifications for Architects and Builders dated 1932, Copyright 1931 by Frank B. Stevens, Jr. of Stevens Master Specifications, Inc., Chicago, Ill., on page 11 of Section 9-0, Steel & Miscellaneous Metals, under Ornamental Metal there appears the following:

WROUGHT IRON

All wrought iron shall be of wrought iron made of soft steel.

EVERDUR METAL

serves *countless* uses . . . better



EVERDUR has come to be regarded as the most advantageous metal to use for an ever-increasing number of widely different purposes. It is considered ideal, not only for bolts, screws and a wide range of fittings that *must* be strong, tough and corrosion-resistant, but for hundreds of uses as variant as sludge pipes, dynamite mixing bowls, tumbling barrels and hot water tanks.

This adaptable Anaconda metal (copper alloyed with silicon and manganese) possesses the strength and welding characteristics of steel . . . and the corrosion-resistance of copper. It is ductile, machines well, and is unusually resistant to fatigue. It is easy to cast, roll, draw, spin, forge and press—and can be worked either hot or cold. Supplied in sheets, wire, rods, tubes, ingots, hot pressed parts and special shapes. Detailed information contained in Publication E-2, mailed on request.

ANACONDA
from mine to consumer

Everdur combines these properties:

1. Strength of steel.
2. Corrosion-resistance of copper.
3. High ductility and fatigue limit.
4. Ready weldability.

Investigate Everdur . . . This metal has solved many problems. It may serve you equally well.

REG. U. S. EVERDUR PAT. OFF.

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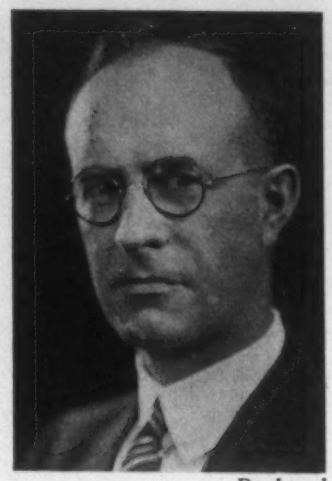
Bachrach
James J. Curran

Wrought Iron
Fact and Opinion

By JAMES J. CURRAN* and E. A. SANFORD**



Bachrach
E. A. Sanford

WROUGHT iron is the oldest form of ferrous metal known to and used by man. Specimens still in existence prove that it was in relatively common use as early as 1200 B.C., and it has been made and used continuously since then. Nevertheless, eminent authorities state in 1932, "There is an utter lack of authoritative published information on the subject of wrought iron."[1] While this comment relates primarily to information on which specifications for quality standards can be based, it is not far from true in the broader sense.

Review of the literature reveals that there has indeed been surprisingly little of importance published on this subject in the past 30 years—which may or may not reflect the progress of the industry during that period. With the exception of valuable contributions by Rawdon and Knight[2] and Gillett[3] much of the information available is in the nature of sales propaganda, inclined to be partisan, and hence not entirely reliable.

As a result, many fallacious opinions have persisted with respect to wrought iron, its manufacture, and properties. Some of these seem to arise from distrust of steel, and everything the steelmaker does, and tend to disparage steel. Others arise from considering that wrought iron is merely a dirty low-carbon steel instead of a product intentionally given certain definite properties.

Since the introduction of the Aston process for the production of wrought iron, interest in this metal has grown in extent and keenness, as evidenced by recent periodical literature. The authors offer some pertinent and timely facts and opinions and at least one interesting suggestion—with regard to free-machining cores integral in wrought iron bars.

In the early ages, wrought iron, or iron, was made by the direct reduction of ore in open fires or rough walled forges, using charcoal as fuel, and this method, with only slight refinement, was practiced up to and into the last century. The conventional modern methods of production are indirect, the ore first being smelted in the blast furnace to obtain pig iron, which is subsequently remelted and refined. In this country, refining is usually carried out in reverberatory "puddling" furnaces, while in Europe variations of the Lancashire hearth are generally used.

Regardless of its origin, or the actual details of its manufacture, wrought iron consists of grains of essentially pure iron, mechanically mixed with slag. It differs from steel and other ferrous metals in that it is not melted and cast, but is produced in the form of a loosely coherent, spongy, plastic mass. This is subsequently welded and consolidated, and partially freed from slag, by compression or hammering, and then rolled into shape. Thus the essential difference between wrought iron and its nearest relative, low carbon steel, lies in the structural characteristics resulting from this method of manufacture. This difference is illustrated in Figs. 1 and 2, representing wrought iron and low carbon steel, respectively, in the finish rolled condition.

In both, the groundmass consists of essentially pure, or nearly carbonless, iron. The wrought iron, however, exhibits characteristic filaments of slag, which are not present in the steel. This slag content, as is generally recognized, is responsible for the laminated or fibrous structure which characterizes wrought iron, and which serves to differentiate it from steel.

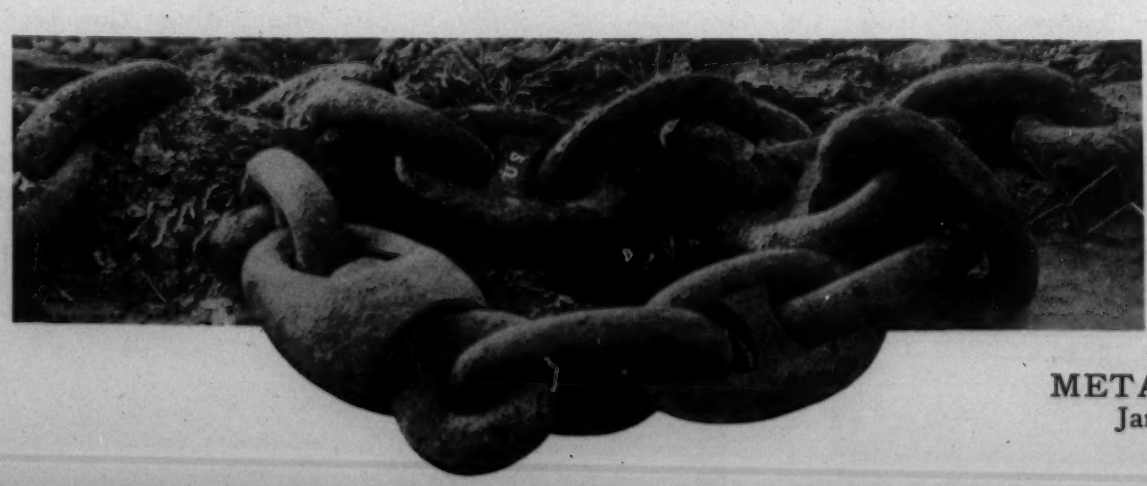
This fibrous structure is shared by several types of ferrous material which are not, however, universally recognized as genuine wrought iron. The first of these is really a secondary metal proposition. Scrap wrought

*Metallurgist, The Henry Souther Engineering Co.
**Chief Chemist, The Henry Souther Engineering Co.

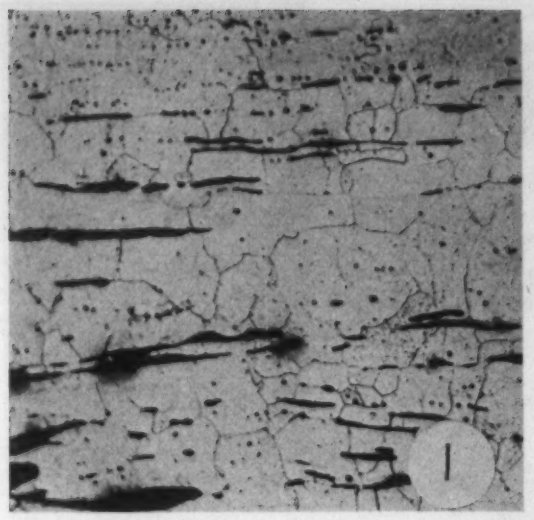
[1] *Report of Committee* A-2 on Wrought Iron, *American Society for Testing Materials,* 1932, 3 pages.

[2] Comparative Properties of Wrought Iron made by Hand-Puddling and by the "Aston" Process. *Metals & Alloys,* Vol. 1, Aug. 1929, page 46; *Bureau of Standards Journal of Research,* Vol. 3, Dec. 1929, page 953.

[3] Wrought Iron—Some Pros and Cons and the Need for Research. *Metals & Alloys,* Vol. 2, Jan. 1931, page 25.



In 1862 this wrought iron chain barred the Mississippi against Union gunboats. Recently, 65 links of this chain, and an anchor, were dug out of the bluffs near Columbus, Kentucky. The chain is said to be "ready for use" and the swivel shown in this photograph is said to move smoothly. (Courtesy A. M. Byers Co.)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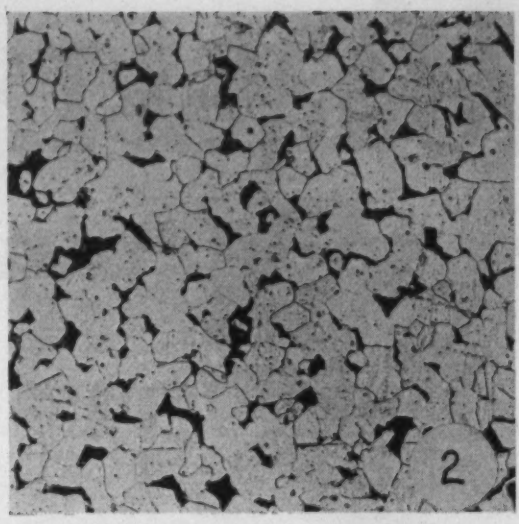
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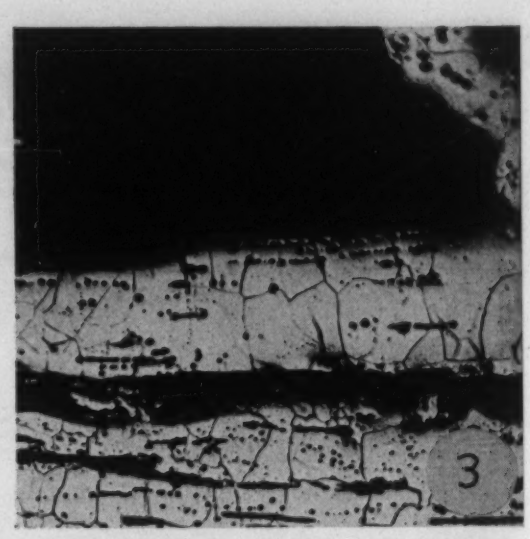
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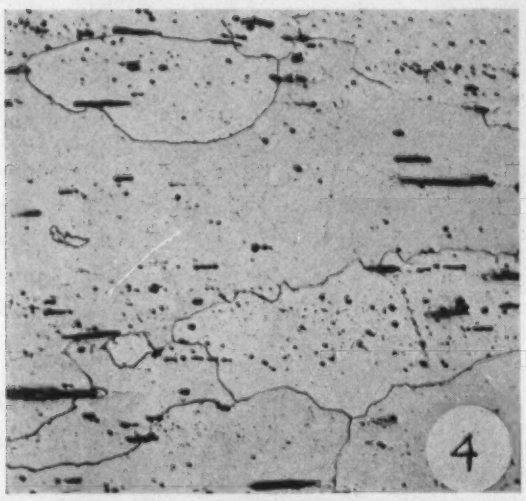
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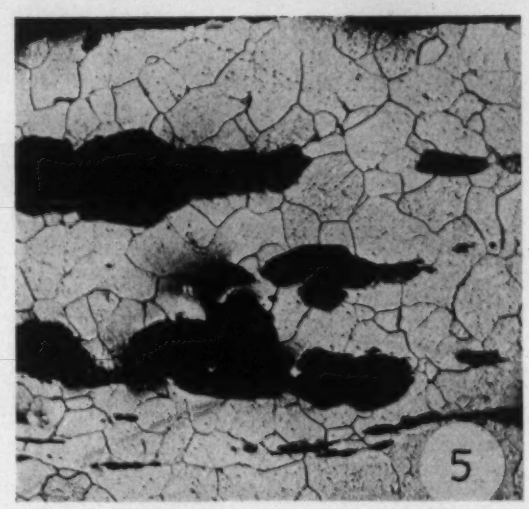
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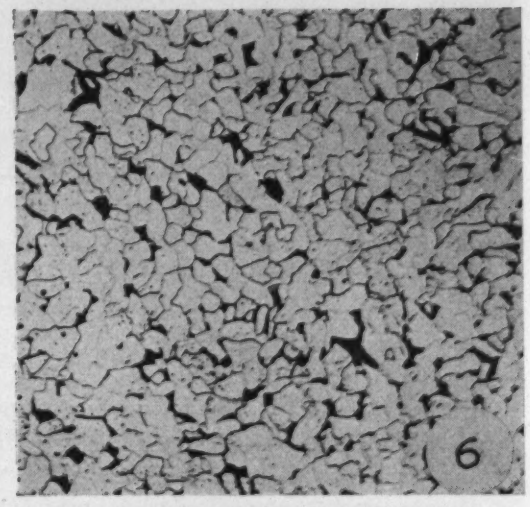
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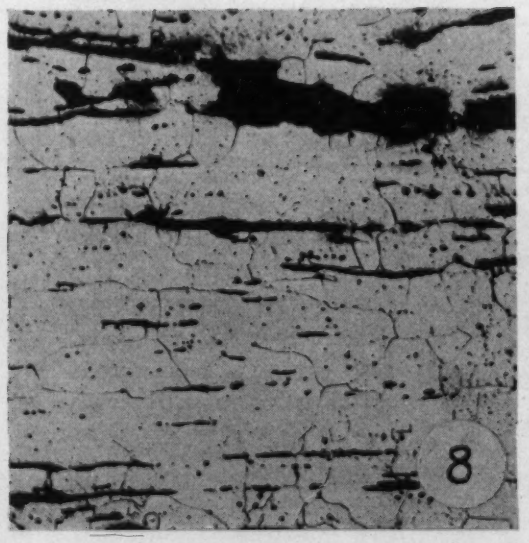
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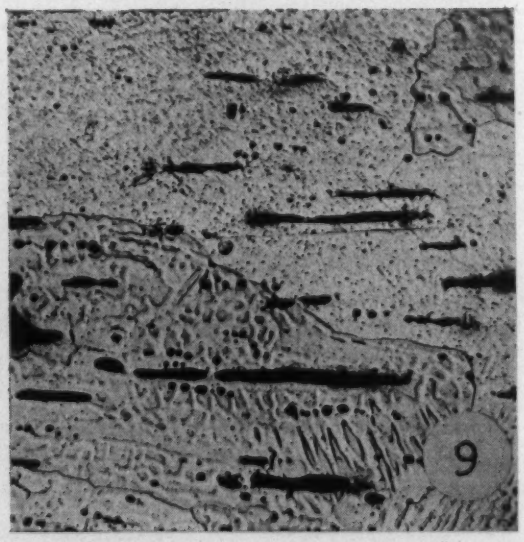
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iron, or steel, or both, are bushelled or faggotted and rolled in the same manner as new muck-bar. If care is taken to include only wrought iron in the piles, the final product must inevitably be genuine wrought iron. If, however, an appreciable quantity of steel scrap is included in the bundle or pile, there is justification for excluding the product from the genuine wrought iron classification.

"Aston iron"—a very recent development—is another fibrous material, identical in structure, composition, and properties with the best wrought iron. The method of manufacture in its first stage is really a steel-making process, to effect the preliminary refining of the pig iron. The molten product is then poured into a bath of molten slag which disintegrates and further refines it, and entraps quantities of slag in the solidified metal, thus producing an exact counterpart of genuine wrought iron. Due to the radical departures from the usual methods of refining, some makers of wrought iron do not as yet recognize it as genuine wrought iron. However, since it has all of the characteristic and desirable properties of wrought iron, it has been so recognized recently in some of the most important specifications, and eventually it must be accorded recognition by all. This newest development is today working profound changes in the industry.

For many years standard specifications have emphasized "all pig puddled iron, free from . . . iron scrap or steel" as an essential safeguard of quality. Recently, in 1930,[4] there was a departure from the time-honored tradition, in eliminating the terms "all pig" and "puddled" from the specifications, in favor of a definition which does not specify the method of manufacture or the raw material of the process.

In the opinion of the authors no reliable data exist to prove that the proscription against iron scrap and steel could not also be eliminated, without sacrifice of quality. The use of cast iron scrap instead of all pig in the

[4] *A.S.T.M. Standard Definition* A 81-30. *A.S.T.M. Standards,* Vol. 1, 1930, page 464.

puddling charge, in small percentages at least, defies detection in the finished product. It is reasonably certain that any difficulties introduced by the use of large percentages could be remedied by proper metallurgical treatment. More difficult problems than this are overcome annually by the steel industry.

The same applies to the use of scrap steel in the piles for rolling, which is considered absolutely ruinous to quality, yet small quantities, up to 10%, can be introduced without ready detection in the finished product. If larger quantities were used, for definite purposes, production costs would not only be lowered, but its usefulness for these purposes might even be enhanced. Certainly the product would not be of lower quality than that resulting when an admittedly poor grade of mechanically puddled iron is box-piled inside walls of supposedly higher quality hand puddled iron. For some special purposes, the centers of wrought iron bars are made of a specially selected grade of iron to facilitate straight and deep axial drilling. It is entirely conceivable that cores of free-machining steels, introduced in piling, might afford even better and more uniform results.

It is the custom of the domestic puddling industry to class its product with, and claim for it, the virtues of ancient iron, such as that of the Delhi Pillar, and of Swedish iron. While these materials are all closely related, and could broadly be classed together, the methods of manufacture and the actual structures are by no means identical. Claims that these materials are identical, and possess similar virtues, shared by no other ferrous metal, are not logical, and tend to contradict other common claims made for wrought iron. For instance, the industry would not countenance for a minute the suggestion that modern wrought iron is as lacking in homogeneity as the Delhi and other ancient irons. Again, Swedish iron contains an appreciably lower content of silicon than puddled iron, and only approximately half the volume of slag. Since the virtues of puddled iron are usually attributed to its slag content, this would mean that Swedish iron is not as good as puddled iron. Such a conclusion is not worthy of consideration; nevertheless this statement is made by inference, when certain claims as to the virtues of slag are put forth.

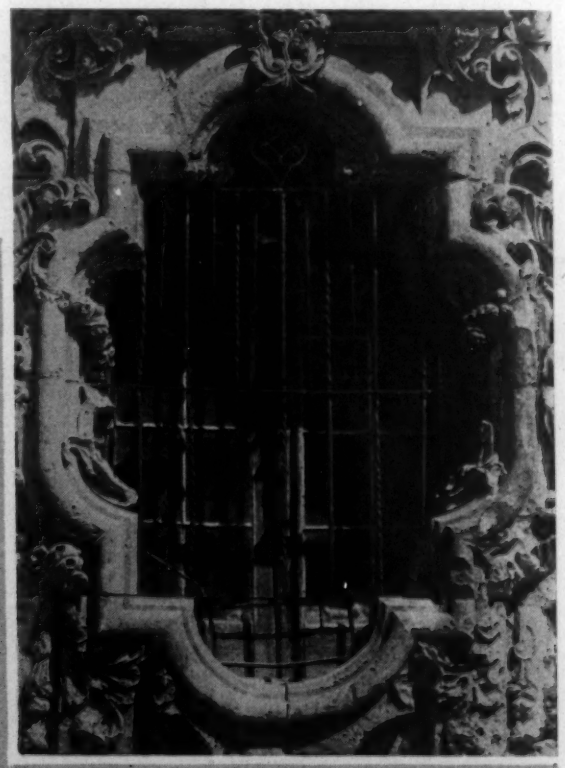
A common fallacy with respect to wrought iron is to the effect that admixed steel can be detected by chemical analysis. The statement generally made is unequivocal: If the iron contains over .10% manganese, this constitutes positive evidence that steel was introduced in piling. Sometimes an even lower figure, .07%, is specified, above which adulteration with steel is indicated. Such misinformation has been circulated for years, in spite of the fact that experienced producers know that manganese can be present in excess of these figures in iron from properly puddled all-pig charges. The literature contains numerous references to this fact.[5,6,7]

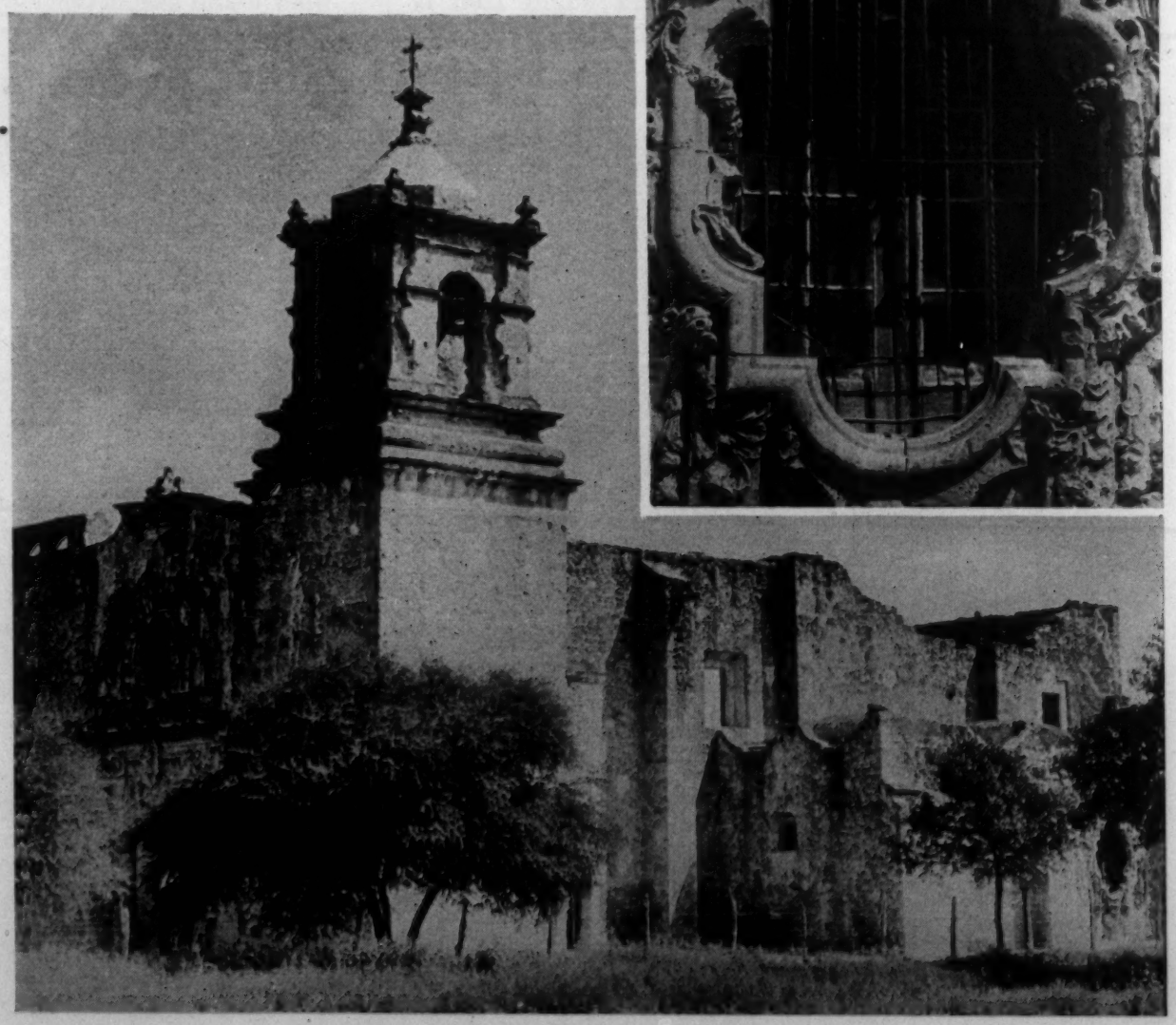
Two examples follow which demonstrate clearly the error of such a claim. The first is a section of an old iron fence rail, 1⅝" square, from the "Green," in Taunton, Mass. According to the proceedings of the Old Colony Historical Society, the iron for this fence was made at the Old Colony Iron Works in East Taunton, and installed in 1841 or 1842. This history was corroborated in 1930, by one of the few living former employees of the company, who also advised that the process used was the pig puddling process. The macrostructure of this specimen (Fig. 10) is characteristic for wrought iron, and indicates that the bar was rolled from a pile consisting of five slabs of muck-bar. The micro-structure (Figs. 3 and 4) discloses wide variations in grain size, and in content and distribution of slag. Chemical analysis shows a manganese content of .12%—in the range that is supposed to prove conclusively the admixture of steel—yet this iron was made 90 years ago, many years

[5]H. O. Hofman. An Outline of the Metallurgy of Iron and Steel. Thomas Todd, Printer, Boston, 1904, page 128.

[6]Major Cubillo. *Journal Iron & Steel Institute*, Vol. 41, 1892, page 248.

[7]J. M. Camp. Making, Shaping and Treating of Steel. 4th edition. Carnegie Steel Co., Pittsburgh, 1925, page 231.





Built in 1701 by Franciscan brothers, the mission of San Jose, near San Antonio, Texas, stands today a picturesque ruin, but the wrought iron cross and arrow surmounting the tower, and the wrought iron window grille, are well preserved. (Note—the broken piece of iron crudely attached at the lower part of the grille is a later addition.)
(Courtesy A. M. Byers Co.)

before the introduction of the Bessemer and open hearth processes.

High carbon content, or streaks of high carbon material in iron, are often stated to be evidence of steel admixture. An example of this condition, coincident with high manganese content, is shown in Figs. 5, 6, and 7. This iron, a high grade Swedish muck-bar, exhibited a manganese content of .19%. The average carbon content (on a sample representing the complete cross-section of the bar) was .28%. The 3 figures show widely different structures, illustrating the variations observed throughout the cross-section of the bar. In Fig. 5, the structure consists of carbonless iron with extremely large inclusions of slag. In Fig. 6 is shown an area in which slag is absent, and pearlite is present to an extent equal to that in a .10% carbon steel. In Fig. 7, some slag is present, but the structure is entirely pearlitic, equivalent to a steel containing .85% carbon. These last two areas are decidedly steely in structure, and might be interpreted to indicate admixed steel, were it not for the fact that Swedish practice does not usually include piling and rerolling, also that the macrostructure of this bar indicated clearly that shearing, piling, and rerolling was not practiced in this instance. Similar high carbon streaks, sometimes with an almost complete absence of slag, are extremely common in high grade Swedish irons, and are often found in our own domestic puddled irons.[2] It is obvious, therefore, that neither the presence of manganese in excess of .10% nor the presence of high carbon streaks, can be taken safely as conclusive proof of steel admixture.

Fig. 10

The presence of bright crystalline areas in the otherwise normal velvety gray fracture of wrought iron is often advanced as proof of steel admixture. One example is submitted which proves that such crystalline streaks or areas are not necessarily due to this cause. The specimen is an old bolt, removed from an abandoned wooden bridge. When broken in tension in the tensile testing machine, this bolt showed a coarsely crystalline structure over 75% of the fractured surface, with the usual gray fibrous structure in the remainder of the fracture—Fig. 11.

Microscopic examination of a longitudinal section through the fracture disclosed no trace of anything resembling a steel structure. In the fibrous portion of the bolt (Fig. 8) the structure is characteristic for normal wrought iron. In the crystalline portion (Fig. 9), the grain is coarse, with shadowy contour lines, or veins, characteristic for high phosphorus wrought iron. Chemical analysis disclosed an average phosphorus content in this bolt of .387%.

Although the condition illustrated is much more marked than ordinarily encountered, it is not uncommon to find isolated areas of extremely high phosphorus content, even in low-phosphorus iron. Where these areas approach .200% phosphorus content, the iron may show crystalline areas on fracturing.[7] The high phosphorus content of the bolt illustrated is undoubtedly responsible for the crystalline fracture observed.

From the foregoing it is evident that the presence of bright crystalline areas is not acceptable as indisputable proof of steel admixture.

The corrosion-resistance of wrought iron compared to steel is a matter of heated controversy among the producers of the competing materials. Wrought iron has shown some excellent records for resistance to atmospheric and soil corrosion, under apparently the same conditions which caused steel to waste away rapidly. At the same time, there are instances on record where steel gave as good, or better service than wrought iron under similar conditions. The literature of the wrought iron and steel pipe companies each abounds in testimonials to the superiority of their own product. There are several reasons which suggest themselves in explanation of this paradox. First, the product of the early days of the steel industry seems to have been responsible for the more or less general belief that steel was decidedly inferior to wrought iron from the standpoint of corrosion-resistance. Second,

In 1884 the U. S. Army built Dock No. 4 at Fort Mason, Calif. The superstructure rests on 10-in. wrought iron piles filled with concrete and topped with wrought iron caps with 4 bolt holes to hold the 12-in. steel I-beams in place. The bearing piles have never been repaired or replaced and are said to be in "first-class condition."
(Courtesy A. M. Byers Co.)

One of the traditional uses of wrought iron — architectural ornamentation — remains as important as ever. The recently erected University of Chicago Field House has ornamental wrought iron hinges.
(Courtesy A. M. Byers Co.

owing to the small-batch methods of production used in the past, and still largely used, considerable variation can and does occur from heat to heat and thus some lots of iron may exhibit markedly different corrosion-resistance from others of supposedly the same quality. In our own experience, the two materials appear approximately equal, with perhaps a slight advantage, under some conditions, in favor of wrought iron.

In this connection the latest report of the Bureau of Standards, on their study of the resistance of metal pipes to soil corrosion,[8] is pertinent. Various kinds of metal pipe, including wrought iron, steel, and cast iron, were buried for 8 years in different types of soil throughout the country. On removal, the data obtained by careful unbiased qualitative examination and quantitative measurements led the investigators to state: "The data thus far obtained do not indicate that any one of the commonly used pipe materials is markedly superior to the others for use underground. In some locations one ma-

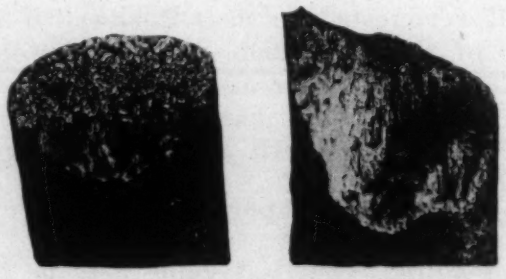


Fig. 11

terial or another appears slightly superior, but the precision of the data are insufficient to justify a comparison of materials." This is the careful statement of men who have followed the investigation since its inception in 1922, evaluating the results of corrosion on all the materials in all of the representative locations selected. The casual observer, examining pipe removed from only one location, might easily grade the materials in order of their corrosion resistance, only to reverse his conclusions completely on examining material exposed in another locality. It should be noted, however, in connection with the quotation above, that the Bureau also warns that the study is not yet complete, and that there is at least a possibility that results of tests over still longer periods of time may indicate that some one material is generally better than the others.

Conclusion

Wrought iron has many excellent properties. It is tough, reasonably resistant to fatigue and impact stresses,[9] easily weldable, and possesses desirable properties for some threading and machining operations. It also has the property of taking a heavier coat (than steel) of zinc in the galvanizing kettle, thus delaying the time when corrosion can reach the base metal, and thereby increasing the service life of the metal. These properties all go to make it a useful metal for many purposes.

However, due to the laborious and small-scale methods of manufacture employed in the past, and to other conditions considered by the industry as prerequisites to quality, it is a relatively expensive and a somewhat non-uniform metal. If it is to develop its maximum utility, and show progress in the future, its cost of production must be reduced and its uniformity improved. To effect this, the industry must discard the old prejudices and fallacies, and copy the ingenuity and progressiveness of the steel-maker. This has been done by one manufacturer in very recent years with decided improvement in uniformity. It is only by similar aggressive and systematic metallurgical attack of their problems that the others can survive.

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Effective January 1st, 1933, the **Associated Alloy Steel Company, Inc.**, closed its offices and thereafter the three constituent companies will market their products through their own sales organizations.

The companies comprising Associated Alloy Steel Company are:

Ludlum Steel Company, Watervliet, N. Y.
Sharon Steel Hoop Company, Sharon, Pa.
Timken Steel & Tube Company, Canton, O.

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M. J. Czarniecki, formerly Manager of Tubular Sales of A. M. Byers Company, has been appointed General Manager of Sales. In announcing the promotion H. W. Rinearson, Vice-President of the Company, stated that the move had been necessitated by the departmentalizing of sales activities due to the increased variety of wrought iron products developed by A. M. Byers Company within the past year. For 68 years the Company manufactured principally wrought iron tubular goods but has more recently broadened its wrought iron products to include plates, sheets, structurals, rivets, forging iron and welding fittings, etc.

[8] K. H. Logan & V. A. Grodsky. Soil Corrosion Studies, 1930. *Bureau of Standards Journal of Research*, Vol. 7, July 1931, page 1.

[9] F. R. Hensel & T. F. Hengstenberg. Effects of Inclusion Streaks on the Tensile and Dynamic Properties of Wrought Iron and similar Materials. *American Institute Mining & Metallurgical Engineers, Technical Publication* No. 488, Oct. 1932, 29 pages.

A Method for Studying Strain Hardening Susceptibility and Aging After Cold Work Deformation

By ALBERT SAUVEUR* and JOHN L. BURNS*

AS A means of cold working, we have used and are using with notable success the Brinell depression. Hardness is then measured by the Rockwell test at the bottom of the depression (Fig. 1) either immediately or after aging at room temperature or at any other temperature for any desired length of time. The simplicity of this method will be apparent and the possibility of applying it to small samples will, we believe, be appreciated. Brinell depressions may be produced under constant load or a constant depth of depression may be obtained by using suitable loads.

Results obtained by subjecting to these tests Armco iron and some of the carbon steel series of the S.A.E. classification will be briefly reported.

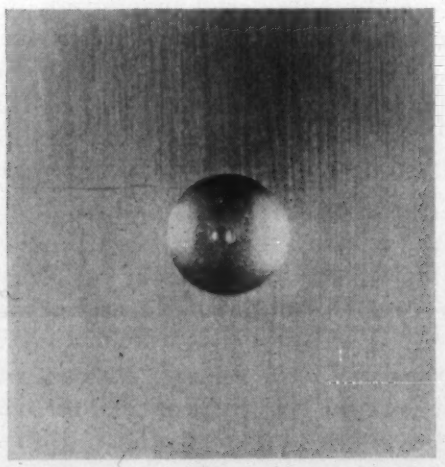

Fig. 1

Strain hardening susceptibility under constant load

All steels after having been annealed, and, therefore, in a pearlitic condition, were Brinelled under a pressure of 500 kg., using a 10 mm. ball, and the Rockwell B hardness of the annealed, unstrained steels were likewise measured. The results obtained are shown in Table 1, the following symbols being used:

D Diameter of Brinell depression.

R Rockwell B hardness of annealed steels.

BR Rockwell B hardness at bottom of Brinell depression.

BR-R Increased hardness resulting from cold working.

$\frac{BR-R}{R} \times 100$ Percentage of increase of hardness. It may be considered as measuring the strain hardening susceptibility of the steel after cold work deformation by a constant load. Obviously, these percentages have a comparative value only. They would be different with different loads.

Table 1.

	D	R	BR	BR-R	$\frac{BR-R}{R} \times 100$
Armco	2.80	43.8	76.8	33.0	75.4
1010	2.50	63.9	87.6	23.7	37.2
1020	2.40	72.6	90.4	17.8	24.5
1040	2.15	79.8	95.9	16.1	20.2
1050	2.10	83.3	97.0	13.7	16.5
1095	1.80	97.3	105.9	8.6	8.8

Table 2.

	P	R	BR	BR-R	$\frac{BR-R}{R} \times 100$
Armco	4,700	43.8	80.9	37.1	84.5
1010	5,600	63.9	86.2	22.3	35.0
1020	5,900	72.6	90.8	18.2	25.1
1040	7,500	79.8	96.5	16.7	21.0
1050	8,600	83.3	98.0	14.7	17.6
1095	11,200	97.3	106.4	9.1	9.0

*Harvard University.

Strain hardening susceptibility for a constant depression

In this method Brinell depressions of equal depth are produced in all steels, necessarily necessitating different loads. In Table 2 P refers to the number of pounds required to produce a depression of 0.3 mm. in depth with a ½″ ball.

Aging after cold work deformation—Resulting from Brinell depressions produced by a constant load

The same steels made pearlitic by annealing and cold worked by Brinelling under a pressure of 500 kg. with a 10 mm. ball were tested for their Rockwell B hardness at the bottom of the depression (1) immediately and (2) after heating for one hour at 100° C. In Table 3, BR_o represents the Rockwell B hardness at the bottom of the depression before aging, $BR_{100°}$ after aging and $\frac{BR_{100°} - BR_o}{BR_o} \times 100$ the percentage of increased hardness due to aging. This last value may be taken as a measure of the aging susceptibility of the steel under the conditions of the test.

Aging after cold work deformation resulting from Brinell depressions of constant depth

Uniform depressions 0.3 mm. in depth were produced by means of a ½ inch ball and adequate pressure. The results are presented in Table 4. BR_{30} refers to the Rockwell B hardness after aging 30 days.

Several features of the aging of steel after cold work deformation have been studied with this method and some of the results obtained will be published later.

Table 3.

	BR_o	$BR_{100°}$	$BR_{100°}-BR_o$	$\frac{BR_{100°}-BR_o}{BR_o} \times 100$
Armco	76.8	86.5	9.7	12.6
1010	87.6	95.0	7.4	8.5
1020	90.4	96.1	6.1	6.3
1040	95.9	99.4	3.5	3.7
1050	97.0	99.6	2.6	2.7
1095	105.9	106.8	0.9	0.9

Table 4.

	BR_o	BR_{30}	$BR_{30}-BR_o$	$\frac{BR_{30}-BR_o}{BR_o} \times 100$
Armco	80.9	88.0	7.1	8.8
1010	86.2	91.3	5.1	6.0
1020	90.8	93.4	2.6	2.9
1040	96.5	98.0	1.5	1.6
1050	98.0	98.8	0.8	0.8
1095	106.4	106.4	0	0

Some Theoretical and Practical Aspects of GASES in Metals

By JACK H. SCAFF* and EARLE E. SCHUMACHER*

JACK H. SCAFF

INTRODUCTION

SINCE Thomas Graham[1] discovered in 1866 that a piece of meteoric iron heated in vacuum yielded 2.8 times its volume of gas,† the solubility of gases in metals has been the subject of a large number of investigations. While these studies have not as yet afforded more than a partial understanding of the nature of the processes by which gases are dissolved in metals, they have yielded considerable knowledge of those factors which determine the extent of such solubility, and thus of the methods by which the amount of dissolved gas can be increased or diminished. At the same time they have shown the importance of dissolved gases in determining not merely the behavior of metals in casting processes, but also the magnetic, mechanical, and chemical properties of metallic materials. It is proposed to discuss, in this paper, theories of the absorption of gases by metals and to review important work on this subject.

The Effect of Gases on the Properties of Metals

The importance of producing sound metals should interest every metal founder in the effects of dissolved gases. Any gas whose solubility is greater in the liquid than in the solid metal may cause the formation of blowholes. The formation of these blowholes, however, can be reduced or prevented by cooling the metal slowly enough through its freezing range to permit the escape of liberated gases. Iron saturated with hydrogen, for instance, will yield a sound ingot if cooled very slowly through its freezing point, while chill casting not only will make the metal porous but may cause an evolution of gas violent enough to throw metal from the mold. This phenomenon is known as "spitting" and is a common occurrence when casting iron, copper, cobalt, and platinum saturated with hydrogen, and silver saturated with oxygen.

The magnetic properties of iron and its alloys are known to be greatly affected by gases. Cioffi, of Bell Telephone Laboratories, has shown that the permeability of iron can be increased to 190,000 by heat treating it in hydrogen at 1500° C.[2] This effect is attributed to the removal of carbon, oxygen, nitrogen, and sulphur. In this field, also, Yensen has done interesting work, details of which are contained in his publications.[3] The permeability of iron can be greatly increased, also, by vacuum melting. Here again the gaseous impurities and those which react to form gaseous products are removed by the treatment.

The influence of oxygen on the carburization of steel is not clearly understood, but its importance has been emphasized by many writers. Grossmann[4] believes that steel absorbs oxygen along with carbon during pack carburization and that this favors a solubility of cementite in α-iron. By this mechanism, he accounts for the phenomenon of split cementite. Guthrie and Wozasek[5] found that the presence of oxygen speeds up the process of gas carburizing, which indicates that oxygen must affect the solubility and rate of solution of carbon in austenite.

EARLE E. SCHUMACHER

The influence of nitrogen on the properties of steel is of commercial importance. It was learned first that nitrogen in steel formed nitrides which were dispersed in the metal and which caused brittleness. Later, nascent nitrogen, obtained from the thermal dissociation of ammonia, was found to react with certain constituents in steel to form an exceedingly hard case. From this discovery, the modern commercial nitriding process has been developed.

Pfeil, Lea, and others have observed that small quantities of hydrogen absorbed by iron during electrolytic pickling appreciably affect its mechanical properties. Pfeil[6] found that the tensile strength of mild steel rods is decreased from 18.34 tons/in.² to 16.69 tons and that the elongation in one inch falls from 62.5% to 10.6%. Normal properties are restored if the steel is allowed to stand for sometime in the air. Lea,[7] also studying mild steel, confirmed Pfeil's elongation data but found only a slight effect on tensile strength. Lea claimed, also, that the hydrogen had only a slight effect on the resistance of mild steel to impact and repeated stresses. The fracture produced by repeated stresses, however, was abnormal.

The amount of hydrogen in electrodeposited metals is believed to affect their properties. Schneidewind[8] showed that the hardness of electrodeposited chromium decreases when the metal is heated to approximately 300°C. This decrease could not be caused by recrystallization of the deposit, for its grain size was not appreciably changed by heating even at 850° C.; nor was the decrease caused by the solution of some constituent which had caused precipitation hardening at room temperature, since quenching and aging did not restore the original hardness. Schneidewind believed that the initial hardness was due to the presence of some volatile constituent, probably hydrogen.

In order to obtain sound castings of copper, it is necessary, in the usual fire refining process, to stop the operation before

METALS are usually not much good unless they are sound. Hence all producers of metals and alloys are interested in avoiding blowholes and other faults arising from gases. In this paper there are included a discussion of the theories pertaining to the absorption of gases by metals and descriptions of actual work illustrating them. Apparatus for the analysis and measurement of gases in metals and for melting metals in vacuum are described. A brief résumé of the literature is included, also, on commercial vacuum melting methods and the results obtained. Vacuum melting is more costly than production by standard methods but the extra cost should be balanced in many instances, by the improved quality of metal obtained. Production of alloys by this process seems justified for such important parts as turbine blades, superheater tubing and aeroplane parts.

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†All gas volumes given in this paper are at normal temperature and pressure.

the oxygen is entirely removed. If the operation were continued further the copper would take up gases from the furnace and unsound castings would invariably be the result. Copper in the tough pitch condition, therefore, contains a nominal quantity of oxygen (0.04%). Although for ordinary uses this product is perfectly satisfactory, when exposed to reducing gases at elevated temperatures, the contained oxygen combines with them to form products which cause embrittlement. For use at high temperatures with reducing gases, therefore, copper must be deoxidized. In the past, metallic deoxidizers were added to the copper during the casting operations, but, in order to assure complete deoxidation, an excess had to be added which reduced the electrical conductivity of the finished product.

Recently, a brand of copper** has been placed on the market which is said to be kept free from oxygen during melting and, therefore, needs no deoxidation. This material can be heated in reducing gases without embrittlement, has electrical conductivity comparable with that of electrolytic copper, and is claimed to be tougher and more ductile than fire refined copper and to have better working properties.

The studies of Tullis[9] and Rosenhain[10] on the gas removal and grain refinement of aluminum have yielded results which may have great commercial importance. Tullis has found that the treatment of molten aluminum with gaseous chlorine completely removes the dissolved gases. Subsequent treatment with boron trichloride causes the formation of small grains in the castings. Rosenhain[10] has reported that both gas removal and grain refinement can be effected in one operation by the use of volatile chlorides such as titanium tetrachloride. Both of these methods are being tested on a commercial scale in England. It is claimed that secondary aluminum, treated in this way, gives strong castings as free from pinholes as does virgin metal. If the cost is sufficiently low and if the industrial hazards attending its use can be controlled satisfactorily, this method of gas treatment should have a wide applicability to refining secondary aluminum.

The descriptions, given above, of the effect of gases on the properties of metals should indicate how important these effects are and how small a quantity of gas may suffice to produce them. It seems necessary, therefore, to consider gaseous impurities along with others in metallurgical studies.

THEORY

The Effect of Temperature on the Solubility of Gases in Metals

Metal founders of early times had great difficulty making castings which did not contain blowholes. Knowing that the solubility of gases in aqueous liquids decreased with increasing temperature, they tried to remove the gases from molten metal by heating to a higher temperature before casting. They found, however, that their product was less sound than before. This suggested to later workers a difference between the action of gases in aqueous liquids and in molten metals and several systematic investigations were begun.

Sieverts, one of the first men to study this problem, found that, in general, the solubility of gases in metals increases with increasing temperature.[11] He found, for instance, that one volume of copper absorbs 0.006 volumes of hydrogen at 400° C., and 0.19 volumes just below its melting point. As the copper melts, the quantity of gas absorbed increases to 0.54 volumes, while at 1550° C. 1.25 volumes are absorbed. The amount of hydrogen absorbed by iron increases from 1.05 volumes for the solid to 2.10 volumes for the liquid at the same temperature.

Some known exceptions to the general rule that absorption of gas increases with increasing temperature are the solubility of hydrogen in palladium, cerium, thallium, zirconium, titanium, tantalum, and vanadium. The solubility changes of hydrogen in palladium are particularly interesting. One volume of this metal absorbs 670 to 800 volumes of hydrogen at 20° C., 50.6 volumes at 138° C., and in the liquid state at 1600° C. only 4.3 volumes.[11]

Since the solubility of gases in aqueous liquids decreases with increasing temperature, and since these data form the bulk of the total available, some workers have suggested that the increase in solubility of gases in metals with increasing temperature is anomalous. No anomaly, appears, however, when the solubility relationship is considered in the light of van't Hoff's law of mobile equilibrium. This law states that, when the temperature of a system in equilibrium is raised, only that reaction can occur which is accompanied by an absorption of heat, that is, an endothermal reaction. The increasing solubility of gases in metals with increasing temperature, therefore, should be taken as evidence of an endothermic reaction rather than as an anomaly.

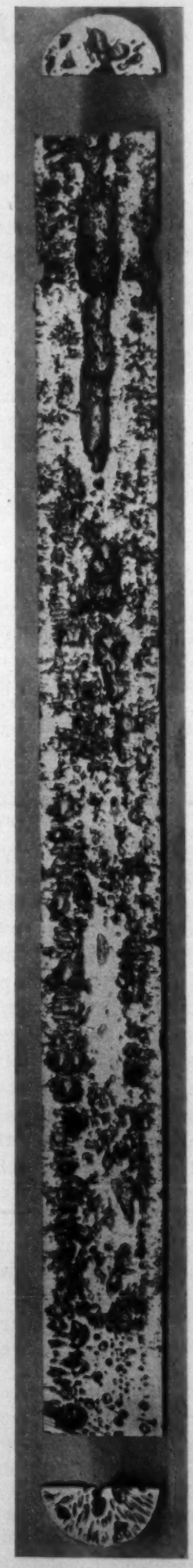
Data are available which show that increasing solubility of gases with increasing temperature is not limited to gas-metal systems. Just[12] has shown that the solubility of hydrogen, carbon monoxide, and nitrogen in carbon disulphide, nitrobenzene, acetone, and other organic solvents increases with increasing temperature. Lannung[13] has reported data showing that the solubility of argon, neon, and helium in methyl alcohol, and acetone increases with increasing temperature. In this respect the gas-metal systems seem to be similar to some of the gas-organic liquid systems.

Another fairly well known influence of temperature on the quantity of gas absorbed by a metal is due to an allotropic change in the structure. That the amount of gas absorbed by a metal changes abruptly when the allotropic form changes, is illustrated by the iron-nitrogen system. 100 grams of iron heated to 878°C. absorb only 1.6 milligrams of nitrogen, but at 930°C., in the γ-modification, it takes up 21.6 milligrams.[11]

The Effect of Pressure on the Solubility of Gases in Metals

The effect of changes in pressure on the solubility of gases in metals has been studied intensively by Sieverts. He made the discovery that the quantity of gas dissolved in a metal at constant temperature is proportional to the square root of its partial pressure.[11] This square root relationship (which may well be called Sieverts' law) emphasizes the difference between the solution phenomena of gases in metals and gases in aqueous liquids, since, in the latter, solubility is proportional to the partial pressure of the gas (Henry's law). There are, however, some gas-metal systems in which solubility does not follow Sieverts' law. It is well known that the solubility of hydrogen in palladium is not proportional to the square root of the gas pressure and this is true also of hydrogen in cerium, thallium, zirconium, titanium, tantalum, and vanadium. These exceptions are the same as those mentioned in the section above on the effect of temperature. These metals are noteworthy for their comparatively great absorption of hydrogen and for their compound formation with it.

Sieverts' law is usually explained by application of the Nernst distribution law, which states that there is a constant ratio between the concentra-



Improperly deoxidized (and consequently very "gassy") experimental steel ingot. Actual size photograph.

**Oxygen Free High Conductivity Copper, produced by the United States Metals Refining Co.

tions of a given molecular species distributed between two phases of a system in equilibrium. Considering, first, molecular oxygen dissolved in a liquid, let P_{o2} denote its partial pressure in the gas phase and C_{o2} its concentration in the liquid. The distribution law is then

$$P_{o2} = kC_{o2} \quad (1).$$

The concentration here is directly proportional to the partial pressure, a fulfillment of Henry's law which is a special case of the distribution law. This adequately describes the solubility of most gases in aqueous liquids.

Considering, now, the solubility of gases in metals, and assuming that molecular gas is dissociated into atoms at the surface of the metal before it is dissolved, let P_{o2} denote the partial pressure of molecular oxygen, P_o the concentration of atomic gas at the metal surface, and C_o the concentration of atomic gas in the metal. Then, according to the law of mass action,

$$P_{o2} = k_1 (P_o)^2 \quad (2).$$

Applying the distribution law to the equilibrium between atomic oxygen at the metal surface and atomic oxygen dissolved gives

$$P_o = k_2 C_o \quad (3).$$

Combining equations (2) and (3) gives

$$P_{o2} = k_1 (k_2 C_o)^2 = K C_o^2 \quad (4).$$

This shows that the square root relationship found by Sieverts can be explained by assuming a dissociation of the molecules of gas somewhere in the process of solution.

Donnan and Shaw[14] applied this type of analysis to the solubility of oxygen in silver and have shown that the solubility is proportional to the square root of the gas pressure not only if dissociated gas is dissolved as described above, but also if this dissolved gas reacts with the silver to form a compound containing one atom of gas per molecule, in this instance, Ag_2O. This conclusion can be reached easily by extending the analysis in the preceding paragraph to include an application of the law of mass action to the reaction between the dissolved atomic gas and the metal. If this is done, it is found that the concentration of compound is directly proportional to the concentration of atomic gas, which has been shown to be proportional to the square root of the gas pressure. Hence the concentration of compound is proportional also to the square root of the gas pressure.

It is apparent from this discussion that data showing the effect of pressure on gas solubility do not show whether gases are dissolved in metals as atoms or as compounds. In order to learn the state in which gases exist in metals, Sieverts[11] studied the solubility of sulphur dioxide in copper. He expected that changes in the pressure would affect the solubility of this triatomic gas differently from that of a diatomic gas. He was surprised, therefore, to find that for this system also the solubility was proportional to the square root of the gas pressure. In this instance, adherence to the square root law could not be explained by assuming dissociation of the gas molecules into atoms.

In this field, Stubbs[15] made some interesting contributions after those of Sieverts. He showed that the freezing point of Cu saturated with SO_2 was depressed 2.54 times as much from that of pure Cu as should be expected from van't Hoff's freezing point formula if the gas remained molecular in solution. If there were complete reaction between the gas in solution and the metal, the freezing point depression should be 3 times that for the existence of molecules only, and the amount of gas absorbed should vary as the cube root of the pressure. Stubbs took the discrepancy in these figures to indicate that about 70% of the dissolved SO_2 reacted with the Cu according to the equation,

$$SO_2 + 6\ Cu = Cu_2S + 2\ Cu_2O.$$

Stubbs also believed that Sieverts' data showed that the solubility of SO_2 in Cu varied as some higher root of the pressure (2.4 root) than the square root and that it supported his theory of partial reaction of the gas with the copper.

Because very little is known of the state in which dissolved gases exist in metals, certain data reported by Franzini[16] are interesting. Franzini believed that, if ionized gas existed in metals, it could be displaced by the action of an electric field. His data on the variation in electrical resistance, caused by application of an electrical field to Fe and Ni wires which previously had been saturated with H, show that the absorbed gas can be displaced toward the negative pole. Thus, evidence of the presence of ionized gas in a metal was obtained.

ILLUSTRATIVE EXAMPLES OF GAS-METAL ABSORPTION STUDIES

The Solubility of Oxygen in Silver

Steacie and Johnson's[17] careful experiments on the solubility of O in Ag form a good illustration of the problems involved in this type of study. Since their work yielded some of the best data available on any gas-metal system, it is reviewed here in some detail.

The principle of their method of determining solubility is a variation of the method ordinarily used. A known weight of silver, contained in a silica bulb, is heated to a given temperature. All traces of gas are removed by evacuation of the apparatus, and then a known amount of purified oxygen is admitted to the silica bulb. After equilibrium between the O and the Ag is reached, the pressure of the gas is measured by a permanently connected manometer. The theoretical pressure of O in the system, assuming none is absorbed by the Ag, is calculated from the quantity of gas introduced, its temperature, and the volume of that part of the apparatus it occupies. The difference between calculated and observed pressures is a measure of the amount of gas absorbed by the metal.

In order to determine the solubility of gases in metals accurately, sufficient time must be allowed for equilibrium to be reached. Although equilibrium was reached very quickly at the highest temperature (800° C.) used by Steacie and Johnson, several days were required at the lowest temperature (200° C.). It is obvious that this long time greatly increases the possibility of errors from leakage of gas into the apparatus. Since Steacie and Johnson were especially interested in solubility at low temperatures, to be certain that no errors were introduced by leakage, they pumped the gas out of the silica bulb and the Ag at the end of each experiment, collected it, and determined its quantity. If the amount of gas collected after an experiment was not substantially the same as the amount introduced originally, the experiment was discarded.

Data relative to the solubility of O in Ag are given in Table I. The solubility can be seen to be proportional to the square root of the O pressure, except for pressures below 10 cm. when the temperature is below 600° C. Here a marked

TABLE I. Solubility of Oxygen in Silver at Various Pressures and Temperatures (Steacie and Johnson)

	$T_1 = 200°C.$		$T_2 = 300°C.$		$T_3 = 400°C.$		$T_4 = 500°C.$		$T_5 = 600°C.$		$T_6 = 700°C.$		$T_7 = 800°C.$	
Pressure (cm.)	Volumes Absorbed (cc., n.t.p.)	Constant	Volumes Absorbed (cc., n.t.p.)	Constant	Volumes Absorbed (cc., n.t.p.)	Constant	Volumes Absorbed (cc., n.t.p.)	Constant	Volumes Absorbed (cc., n.t.p.)	Constant	Volumes Absorbed (cc., n.t.p.)	Constant	Volumes Absorbed (cc., n.t.p.)	Constant
P	Q	$\sqrt{P}/Q$	Q	$\sqrt{P}/Q$	Q	$\sqrt{P}/Q$	Q	$\sqrt{P}/Q$	Q	$\sqrt{P}/Q$	Q	$\sqrt{P}/Q$	Q	$\sqrt{P}/Q$
5	0.030	74.5	0.021	106.5	0.020	112.0	0.022	102.0	0.033	68.0	0.048	46.7	0.088	25.5
10	0.050	63.4	0.032	90.8	0.031	102.3	0.034	93.2	0.047	67.5	0.068	46.6	0.124	25.6
20	0.071	63.3	0.045	91.0	0.044	102.3	0.048	93.4	0.066	67.9	0.096	46.7	0.175	25.6
40	0.100	63.5	0.070	90.5	0.061	103.9	0.067	94.5	0.093	68.1	0.134	46.3	0.247	25.7
80	0.142	63.2	0.097	91.7	0.087	103.0	0.095	94.3	0.132	67.9	0.193	46.5	0.354	25.3

divergence from the square root law appears, which might be explained by assuming that these measurements were made before equilibrium was established. These data are plotted, in Fig. 1, to show the variation of solubility with temperature, giving pressure as a parameter.

The curves of Fig. 1 differ from those for other systems in that a minimum point occurs at about 400° C. It would be logical to explain this minimum as an adsorption effect, but Steacie and Johnson found that, below 400° C., the solubility of O in 2 samples of Ag with different ratios of surface to volume was the same. If an appreciable part of the gas had been adsorbed on the surface of the metal instead of being in solution, a difference in apparent solubility should have been observed. They suggested, then, that the minimum point might indicate a change in the Ag from one allotropic form to another. This explanation was found unsatisfactory later, because experiments showed that the solubility of H in Ag passes through no minimum as does that of O.

Mechanism of Solution of Oxygen in Silver

Following Langmuir's conception of the mechanism of adsorption Steacie and Johnson[18] proposed an explanation of the mechanism of solution of O in Ag in which the solubility minimum is attributed to a change in the form of the O in solution. While a detailed criticism of this explanation would require more space than is available here, it seems unsatisfactory to the present authors, who wish to suggest the following alternative explanation.

Suppose that dissolved gas is held within the interior of the metal, and that it is in equilibrium with that adsorbed on the surface. Now the concentration in the interior which will be in equilibrium with a given surface concentration increases with increasing temperature. The surface concentration, however, which is due to adsorption, will itself decrease with increasing temperature. Hence the final equilibrium depends on 2 factors which vary with temperature in opposite directions. Below 400° C. surface concentration may be the controlling factor. Thus, as the temperature rises towards 400° C., the surface concentration decreases faster than the dissolved gas in equilibrium with it increases. Hence the solubility decreases with increasing temperature. Above 400° C., the amount of dissolved gas in equilibrium with the adsorbed surface gas increases faster with increasing temperature than the surface concentration decreases, and the amount of gas dissolved increases with increasing temperature. Theoretically, this explanation applies equally well to other gas-metal systems and would lead one to expect solubility minima in them. These minima, however, in some systems may be at temperatures below the range subject to investigation.

The Rate of Solution of Oxygen in Silver

In addition to their determination of solubility of O in Ag, Steacie and Johnson made very careful measurements of its rate of solution.[17] These data support their assumption that the process of solution consists first of saturation of a surface layer of the Ag with O and then diffusion into the metal. If diffusion is the limiting factor in rate of solution, the data obtained should be expressed by the equation:

$$K = \frac{1}{t} \log \frac{s}{s - x} \qquad (5),$$

where K is a constant, t is time, s is the concentration of a saturated solution of gas in the metal, and x is the average concentration of gas dissolved in the metal at time t. Steacie and Johnson found that their data did fit this equation, if the first few points were neglected, and they plotted curves showing the change in rate of solution with temperature.

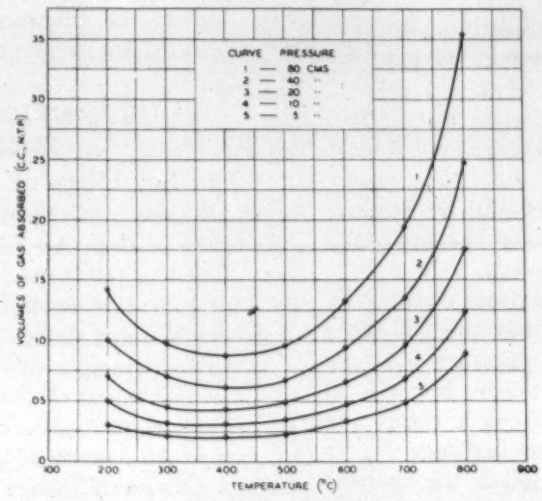


Fig. 1. Solubility of Oxygen in Silver as a Function of Temperature with Pressure as a Parameter (Steacie and Johnson)

THE ANALYSIS AND MEASUREMENT OF GASES IN METALS

Theory

The most obvious method of determining the quantity and composition of gases in metals consists of melting a sample in vacuum and collecting, measuring, and analyzing the liberated gases. The experimental procedure is difficult, however, and the inherent errors are of such magnitude that most results are at best only qualitative.

One of the principal sources of error in these experiments is the evolution of gases from furnace walls and hot refractories. When the metal is heated by induced high frequency electric currents, however, this error can be reduced, and it can be minimized further by maintaining a large metal to refractory ratio. Another source of error, of equal importance, is introduced when metal vapor condenses on the comparatively cool parts of the apparatus and reabsorbs some of the gas previously liberated. Although this effect results usually from heating the metal in a high vacuum to too high a temperature, it is not easy to eliminate, because, when the temperature is reduced, the evolution of gas becomes too slow and the recovery of gas incomplete. Errors also are introduced by gaseous products often formed by reactions between impurities in the metal melted and the refractory oxides of the crucible. This occurs, for instance, when melting steel in a refractory oxide crucible. The C reacts with the oxides to form CO, CO_2, or both.

Apparatus and Method

Despite difficulties and errors in the determination of gases evolved from metals melted in vacuum, some special vacuum melting procedures have been devised which can be used satisfactorily for certain gases. A method of determining O, N, and H in ferrous alloys, developed by Jordan[19] and his co-workers, and by Oberhoffer,[20] is now widely used.

In the method of Jordan, the samples to be analyzed are melted in vacuum in a gas-free Acheson graphite crucible. The liberated gases consist of CO, N, and H. The CO is formed by interaction of O (or oxides) from the metal with C from the crucible. The N, which may originate from dissociation of nitrides, is evolved from the metal without chemical reaction with the crucible. The form in which H exists in the metal is unknown. These gases are pumped away from the melting compartment and collected for analysis. The CO and H are oxidized to CO_2 and H_2O, respectively, by passing them over heated copper oxide, and their quantities are determined by absorption in suitable absorbents. The residual gas, N, is determined by a volumetric method.

The Jordan apparatus with some modifications,*** as shown in Fig. 2 is used at Bell Telephone Laboratories. The most important change is in the method of determining the weights of CO_2 and H_2O formed during the analysis. In Jordan's apparatus, the absorbents for CO_2 and H_2O are contained in weighing tubes which must be weighed along with the absorbent and the absorbed gas. In most experiments, the weight of gas absorbed is only a few milligrams and an elaborate technique is required, therefore, to weigh this small quantity when contained in a tube whose weight is relatively large. In the new modification, in order to minimize errors in the measurement of weight, and to simplify the technique required, a quartz spring balance has been substituted for the weighing tube. The absorbent for the gas is contained in a light glass basket attached to a quartz spring. The extension of the spring is measured with a cathetometer and the weight of gas absorbed determined from calibrations. Springs are made in various

***These modifications were developed by Mr. E. S. Greiner who will describe them in the near future in a paper giving the complete details, together with a critical study of the method.

sizes so that one can always be found to fit the range of weights it is necessary to measure.

VACUUM MELTING

Apparatus and Method

In order simply to prepare metals as gas-free as possible, at Bell Telephone Laboratories a special vacuum furnace was devised and constructed which has been extremely satisfactory and helpful in studying the effects of gases on the properties of metals. A schematic diagram of this furnace is shown in Fig. 3. The metal to be melted is contained in an alundum boat which is placed horizontally in an alundum thimble. The alundum thimble acts as a radiation shield and is supported concentrically on alundum cradles in a horizontal pyrex glass tube. The metal is heated inductively by high frequency currents supplied by a 35 KVA Ajax Northrup converter.

After the furnace is charged, the pyrex tube is sealed off with an oxygen hand torch, and is baked out at 450° C. by a nichrome wound furnace, the position of which is interchangeable with that of the high frequency induction coil. The pyrex tube is baked out for several hours so that subsequent heating by radiation from the melted metal causes no appreciable evolution of gas.

The gases given up by the liquid metal are pumped out of the system by a 4 stage Gaede mercury diffusion pump backed by an oil pump. A liquid air trap prevents mercury vapor from entering the furnace tube and increases the efficiency of the pumping system by removing water vapor and CO_2 from the gases to be pumped out. Rough measurements of gas pressure are made with a McLeod gage on the pump side of the liquid air trap, but measurements of low pressures are made with an ionization manometer on the furnace side.

With this furnace, and using clean alundum parts, metals can be melted with very little contamination of any kind. Cu and Fe have been melted under a pressure never rising above 1×10^{-2} mm. Hg. and having a final value of 1×10^{-5} to 1×10^{-6} mm. Hg. Even lower pressures can no doubt be obtained by cooling the pyrex furnace tube more effectively, as by use of a water jacket, and by using gas absorbing chemicals such as activated charcoal.

It has been found with this furnace that, even when melting iron, the temperature of the glass furnace tube never rises above 150° C. Since pyrex glass does not soften below 500° C., it should be possible to melt metals with higher melting points than that of iron.

In this furnace, a horizontal boat rather than a crucible is used to hold the sample for 2 reasons. First, the surface area of metal is greater and the pressure head of metal less so that the melt is degasified more rapidly than it would be in a vertical crucible. Second, very much smaller and less troublesome pipes form in horizontal ingots than in vertical ones.

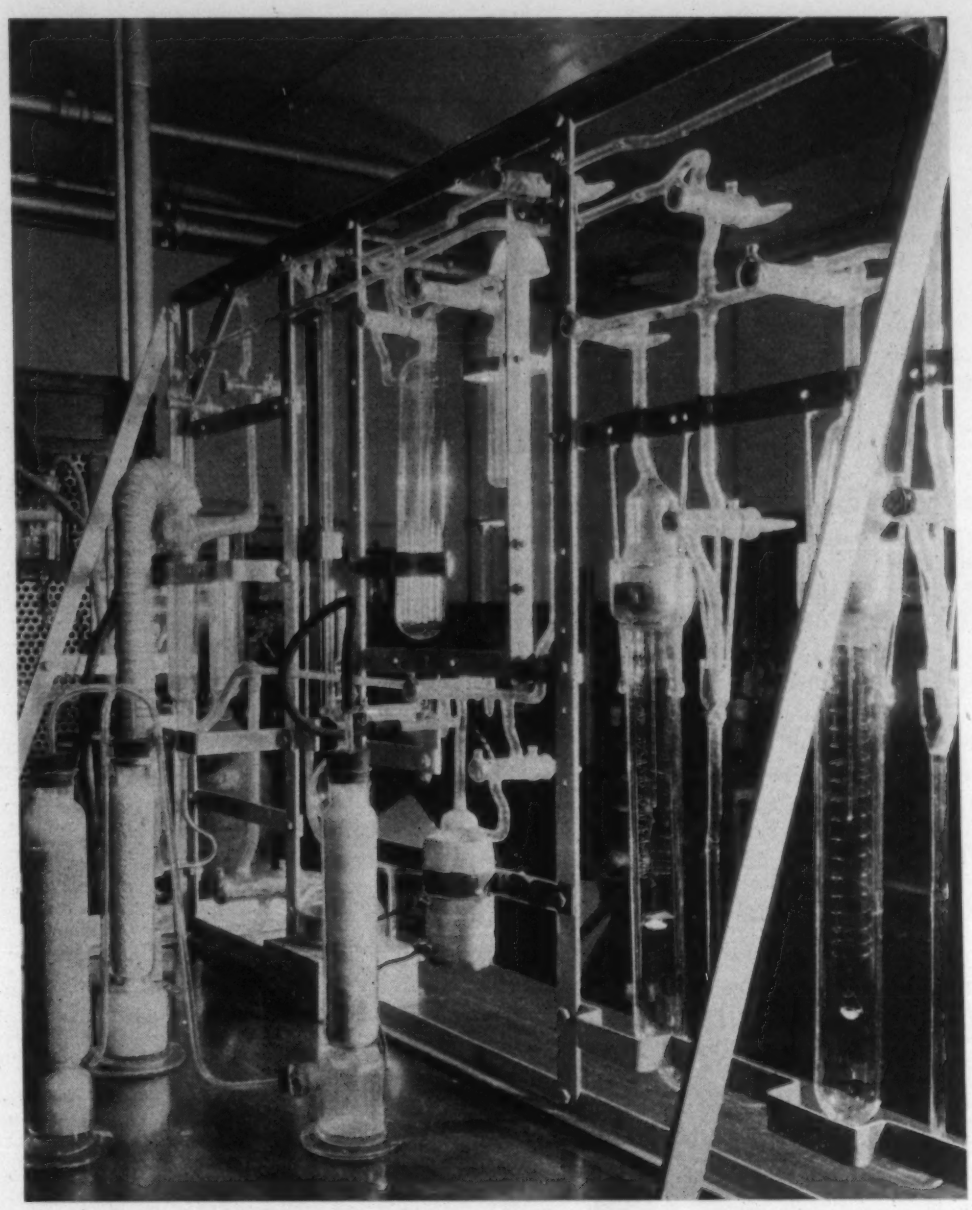


Fig. 2. View of Gas Analysis Apparatus Showing Quartz Spring Balances. Modified Jordan Apparatus for the Determination of Oxygen, Nitrogen, and Hydrogen in Ferrous Alloys. Quartz Spring Balances shown at right.

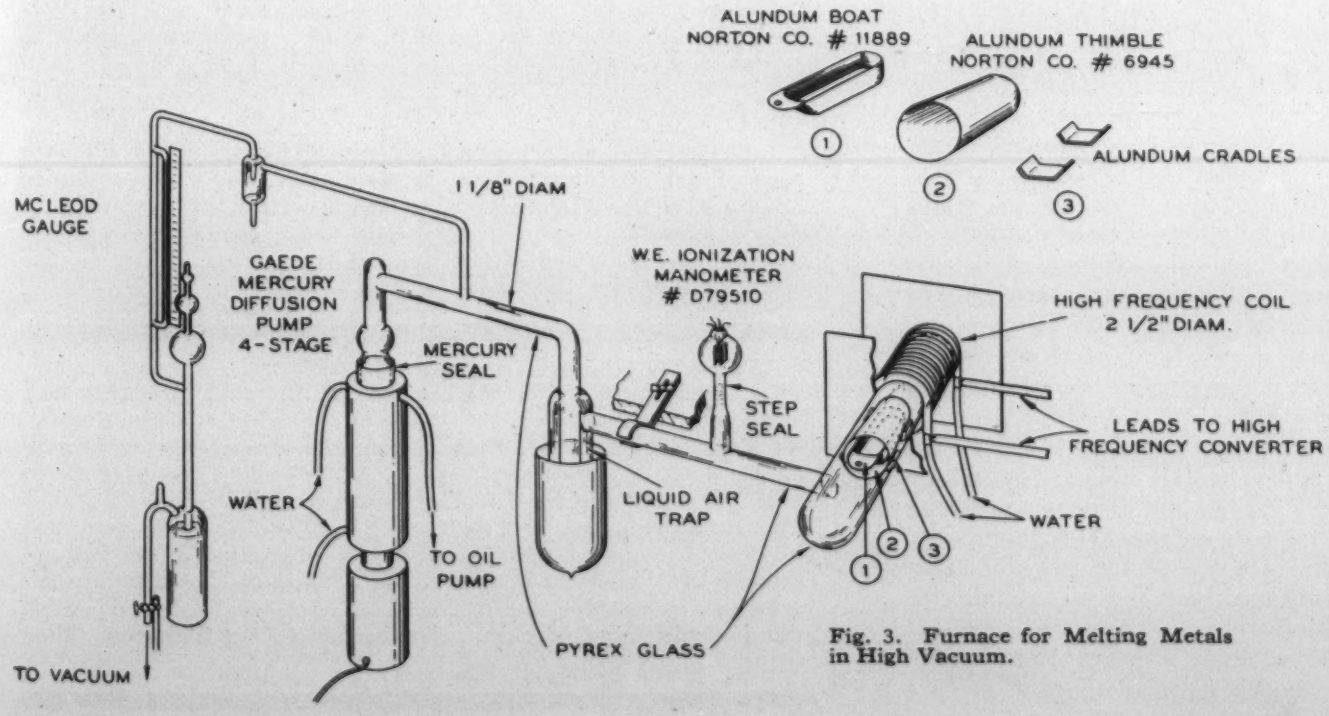


Fig. 3. Furnace for Melting Metals in High Vacuum.

Commercial Vacuum Melting

Vacuum melting on a commercial scale was developed in Germany during the war because of the need for a method by which the composition of alloys could be accurately controlled. The scarcity of platinum, for instance, necessitated the commercial production of substitute alloys for thermocouples which could be used, without calibration, in direct reading instruments. From the small furnaces used for this work, vacuum furnaces capable of handling up to 4 tons have been developed.

A brief description of one of these furnaces and

of the obstacles encountered in their development has been given by Rohn in his publications.[21] The furnace described by Rohn operates by high frequency induction. It has a horizontal, ring-shaped melting chamber surrounded by the primary induction coils and an iron core. The whole is enclosed in an air-tight casing arranged so that it can be tilted about a horizontal axis. Two molds are fastened on opposite sides of the casing through air-tight connectors. When the charge is molten and degassed, the ingots are poured by tilting the entire furnace first to one side and then to the other.

Rohn claims that by dividing the iron core into several parts, a homogeneous field is obtained while there is only a small induction effect in the metal casing. The primary coil, also, is composed of 4 separate units which can be connected in series or energized separately. Energizing only one unit of the primary, it is claimed, causes vigorous stirring of the molten charge thus facilitating the degasification. When the units are energized in series, the uniform field obtained causes but little stirring.

One of the chief obstacles it was necessary to overcome during the development of these large furnaces was lack of a satisfactory vacuum casting procedure. Rohn and his coworkers found that, if a normal casting procedure were followed after all the gases were removed from a charge of metal, ingots were obtained with such large shrinkage cavities that working them was impossible. When using iron or sand molds the formation of these cavities could not be prevented. A vertical water-cooled, copper mold was developed, however, that was satisfactory when the melt was poured slowly.

Another obstacle encountered was in obtaining a satisfactory lining for the vacuum furnaces. A moistened material, tamped into place, could not be used because of the difficulty in removing water vapor. The method adopted consisted of packing the regular refractory, as a dry powder, between the outside furnace wall and a template made of the same metal as the charge to be melted. The temperature of the charge was then so controlled that the refractory powder sintered before the template melted.

The Advantages of Vacuum Melting

In addition to freedom from blowholes in castings, one of the main improvements effected by using vacuum furnaces for melting metals is the degree of quality and composition control which can be attained. With this method, no gas can interact with constituents of the melt to cause composition changes, and the melt can, therefore, be kept liquid for long intervals of time. This allows the suspended particles of slag and oxides to rise to the surface, and results in ingots freer from inclusions. Furthermore, the usual deoxidation methods can be dispensed with. For instance, the iron oxide in molten steel is completely eliminated by reaction with carbon, and therefore, no deoxidation is necessary. Likewise, for non-ferrous metals, no deoxidizers are needed, for during vacuum melting no oxidation of the melt can occur. Thus, inclusions from these sources also are avoided.

In a recent publication Rohn[22] states that Fe, Ni, and Cu may be freed of O by dissociation of their oxides during vacuum melting. According to our experiments, however, when tough pitch Cu is melted under a pressure even as low as 1×10^{-5} mm. Hg. approximately, the O is not removed. After this treatment the material is still embrittled by annealing in H. This failure of the oxide to dissociate may be reasonably ascribed to a reduction in dissociation pressure caused by solution of the oxide in molten Cu. This explanation is supported by the thermodynamical calculations of many workers.[23] Furthermore, as the oxide solution in liquid Cu becomes less concentrated, its dissociation pressure is lowered so that removal of the last traces of O by dissociation becomes exceedingly difficult.

Rohn[22] has reported that magnetic materials, thermocouple metals, metals for vacuum tube parts, metals for sealing through glass, and Ni-Cr alloys for heating elements are being produced advantageously by vacuum melting. He claims, also, that all of the working properties of the Ni-Cr series of alloys are improved by vacuum melting and that alloys containing up to 33% Cr can be worked satisfactorily.

Concerning the economy of vacuum melting, Rohn points out that production by this method is more costly than production by standard methods. He states that vacuum melting increases the cost of metals 10 cents a pound when using a 4 ton furnace and starting with a cold charge. This can be reduced to 1 or 2 cents a pound if the vacuum furnace is used only for the final refining treatment of molten charges. This extra cost should be balanced, in many instances, by the improved quality of metal obtained. Rohn's expectations, which seem to be justified, are that alloys can be made by this process for highly important parts such as turbine blades, tubing for superheaters, and aeroplane parts.

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At the 1932 World Foundry Congress in Paris **Dr. F. Renaud,** an abstractor of METALS & ALLOYS, was awarded the first bronze medal given by the Association Technique de Fonderie de France.

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Joseph S. Pecker has been made president of the Research & Manufacturing Corp., Philadelphia. This organization will bridge the gap between inventors and manufacturers lacking research departments.

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The Advance Pressure Castings, Inc., New York City, have appointed the following sales representatives: F. X. Morris, Delaware County, Pa.; L. E. & L., Sales Engineers, Highland Park, Mich.; W. R. McDonough & Co., Cleveland, O.; B. J. Steelman, Chicago, Ill.; A. G. Werner, St. Louis, Mo.

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Nelson E. Chance, formerly district manager of the Houston office of The Brown Instrument Company, has been appointed Assistant Sales Manager, with headquarters at Philadelphia. Mr. Chance has been with the Company over 10 years and for 7 years was manager of the district comprising Texas, Louisiana and Southern Arkansas.

Andrew Thompson, prominent in the iron, steel and ceramic fields, died suddenly at his home in Buffalo on December 8th. Mr. Thompson, who was 55 years old, graduated from Princeton University in 1899. From college he entered the employ of the Embossing Company, Albany, N. Y. and at the time of his death, he was president of that company.

In 1912, he came to Titanium Alloy as Vice-President and General Manager. At that time the sole product of the organization was Ferro Carbon Titanium. Through Mr. Thompson's foresight, exhaustive analysis and research was instituted which added a wide line of ceramic materials to the Titanium Alloy output.